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A NEW CONTROL STRATEGY OF INDOOR AIR TEMPERATURE IN AN AIR-CONDITIONING SYSTEM

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ABSTRACT

This paper proposed a new method to control the indoor air temperature of air-conditioning systems in offices based on resident's feeling of comfort instead of traditional fixed indoor air temperature control method. Combined with human's psychological reaction and the new signal transfer technique, the room air temperature is controlled by the signals sent from human body so that the resident's actual requirement is satisfied without compromise. For application of this strategy, we suggest to use the temperature of wrist skin at inner side as the representative index to control the air conditioning system. Three experiments on human body temperature are conducted, their results shows the effectiveness of the selected measuring point.

1. INTRODUCTION

Nowadays, the main target of air conditioning controlling and adjusting system is to maintain the indoor temperature and humidity at an expected level. In a manufactory, the technique process always determines values of these air parameters, thus production can be output with high quality. However, for air conditioning systems aimed at thermal comfort of occupants in the building, things are different, people instead of production become the determinative. To find the value of air parameters that can meet occupants' thermal comfort demand, many efforts have been made. In most cases, studies are based on laboratory and/or field works in which people are thermally investigated under different condition. Then, the collected data are statistically analyzed. As a result, a range/value is suggested as thermal comfort range/value. In a traditional air conditioning PID control strategy, this becomes the set value.

For big commercial building like theater, supermarket, airport, the traditional control strategy can satisfy majority of its occupants; but for small single room, office for personal use, it may not work well in terms of thermal comfort and energy efficiency, simply because the thermal demand of the occupant in room is changing instantaneously, which has close relationship with his/her updated level of activity, cloth, hungry, anxiety. One most common experience of occupants in a room applied traditional air conditioning control strategy is that in summer when people have a sleep, if the set room temperature is too high, he may feel too hot and wake up; on the contrary, if the set room temperature is too low, he may feel too cold and get a fever. This example shows the defection of traditional air conditioning control strategy, which doesn't fully consider its service targets, the occupant, in the control loop.

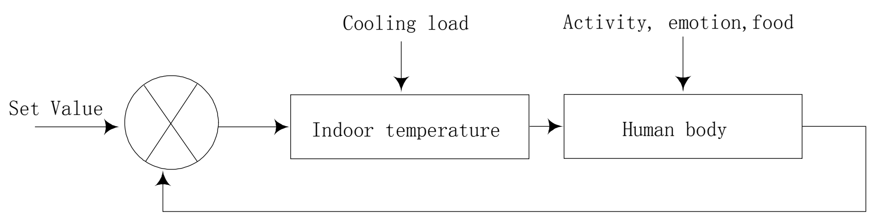
In this paper, an idea of new occupant-oriented control strategy is suggested. In this strategy, the measure point is on the body of people instead of a typical point in the room, thus reflects the real thermal demand to comfort the people.

2.Suggested control strategy

The suggested control strategy is based on principles of physiological reaction of human body, and can be apply in single office room or resident house. The key idea of this new strategy is that the control of air conditioning system is objected to the thermal comfort of its occupant directly. The cooling valve will adjust automatically due to the direct feeling of its residents.

Figure1 shows the control loop of this new control strategy. For a traditional control strategy, there is no link of human body, the thermal comfort of resident is indirectly considered and the strategy is objected to technique process in some manufactory. This suggested control strategy includes the human body, which is the service target of a residential building. The added link together with previous control loop becomes the new control strategy, which can meet the thermal comfortable demand of human body in maximum.

Figure1 Control Loop of suggested control strategy



3. Mechanism of sensing and adjusting to environmental temperature of human body

Human, which evolves millions of years in the earth, has developed his own mechanism to adjust himself to the environmental temperature and his personal feeling to maintain his life and body temperature, just as animals have done shown by Miu Duansheng (1976) [5] and Qin Junde (2000)[4]. He will change his body thermally to a certain range when the environmental temperature is changing. One example is in taking care of a baby. When you notice his scrotum is contract, you know he is feeling cold; when flabby, he is feeling hot. Although the baby doesn't say a single word, the adults can choose to cover more cloth or cool the baby's body due to this obvious physiological phenomenon. It was shown that laws exits in human body temperature adjusting (Liu-li *et al.*,1982)[3].

Skin temperature is evidently lower than that of inner organism. In the body inner, the temperature is almost of uniformity, which we call core temperature. The nearer the measure point to the body surface, the lower the body temperature is, or in a other word, the organism shell is comprised of tissues in lower temperature, which we call shell temperature. The shell temperature is not always the same when different body parts are measured, generally temperature of hands and feet are relatively higher and head is of highest. Recta temperature is often regarded as core temperature. However, it is difficult to measure precisely due to effect of sensor length and/or dejection.

The warmness or coldness sensed by human body is surely related with environmental temperature, but also be affected by other factors like wind velocity or environmental humidity. Considering the effect of humidity to the body heat loss, when humidity is low, with the increase of environmental temperature, the heat loss from radiation and conduction is decreased while the heat loss from the evaporation is increasing, when the temperature goes up to a certain point, the organism is in the state of being heated; when humidity is high, the heat loss either from the radiation and conduction or evaporation does not change dramatically.

In this point, the heat loss will be different with the environmental condition. For a separated person, the more the heat loss, the colder he feels; the less, the warmer. Since the heat loss can be remain the same value while temperature, humidity and velocity are changing, and the feeling may not show much difference in terms of warm or cold. So in order to measure the real feeling expressed in parameter of temperature, effective temperature (EF) is defined. Supposing relative humidity is 100%; velocity is 0m/s; dry ball temperature is 10°C. Then the value of EF in this condition is 10°E. Even though, the environmental parameters may change for some reason, if the heat loss remains the same, the value of EF still remains 10°E. In an air-conditioned room, the typical velocity is less than 1m/s, and the EF can be defined in equation 1

$$EffectiveTemperature = 0.4 \times (T_d + T_W) + 4.8 \qquad (1)$$

T_d :dryball temperature (°F)
T_w :wetball temperature (°F)

Discomfort Index (DI) ban be defined in equation 2

$$DiscomfortableIndex = 0.4 \times (T_d + T_W) + 15 \qquad (2)$$

When temperatures expressed in Celsius temperature scale, refer to equation 3

$$DiscomfortableIndex = 0.4 \times (T_d + T_W) + 40.6 \qquad (3)$$

Table 1 shows the percentage of peoples who feel uncomfortable in different DI value.

Table 1 Percentage of peoples who feel uncomfortable in different DI value

DI	***Percentage (%)***
66~74	0
75	10
77	67
>80	100

This phenomenon can be explained by structure of human body. Xu Yuwei *et al.*(1997)[6] and Chen Xiaochun *et al.* (2003)[1]showed that there are two kinds of receptors to sense warm and cold separately for man. All these skins receptors are tiny dots distributed on the skin, in which the cold receptors are four to ten times of warms. When being stimulated, these receptors will discharge, and the discharging frequency depends on the temperature. The cold and warm receptors will discharge at maximum frequency at 32°C and 40°C respectively. Liu Jing and Wang Cuncheng (1997) [2] showed that the thermoregulation center is located in the brain, of the lower side of thalamencephalon. The signals from millions of skin temperature receptors are send to this center. After analyzing these signals, the brain can regulate the muscles, sweat glands or blood vessels to keep the body temperature at normal level. The process of sensing and adjusting is similar to that of a thermostat, but in a more complex and precise level.

4.Experiment results

According the temperature sensing mechanism of human body, the ideal sensing point is in the human brain. It is the location where the human's real feeling comes out. By measuring the reaction of brain, we can know the real feeling of subjects accurately. Limited by technology in medicine and electronics, it is obviously unpractical. A new method that can meet the demand both technically and economically is suggested.

One possible way is to measure the discharging reaction of a single cell on human skin, for the temperature sensor of a cell can change it's discharging frequency. But the measurements are only limited in laboratory since the shield room and highly sensitive equipments are prerequisite in detect extremely weak signal.

Another substitute is to measure the skin temperature, since it can reflect the feeling of human body to the environmental temperature. In measuring some certain part of skin, we don't need medicinal surgery to the human brain; furthermore, the technology in measuring temperature is fully developed and conveniently to perform. We select skin of wrist at inner side for following reasons: 1) with plenty blood vessels 2) convenient to measure. To denote the effectiveness of this selected location to the subjective feeling, three experiments on human body are conducted. All these three experiments are performed in July. In sensing the temperature, the platinum sensing resistor, Pt 100 is pasted on inner surface of wrist, then a dry towel wraps around the wrist as insulation.

Table 2 shows the results of measured temperature when subject goes outdoors from the air-conditioned room and then return indoors. We can see from the test results that wrist skin temperature can also make a little change due to the changing of environmental temperature. When feeling hot, the skin temperature will increase and vise versa. Furthermore, the wrist skin temperature can reflect thermal comfort.

Table 2 Test results of experiment 1

Time	***Feeling***	***Skin temperature***	***Note***
13:02	Comfortable	35.24°C	Room temperature 26.2°C
12:04	Slightly hot	35.50°C	Going outdoors
13:06	Slightly hot	35.50°C	Outdoor temperature is 37.5°C, with direct sunlight
13:09	Hotter	35.76°C	
13:12	Continuously getting hotter	36.02°C	
13:17	Moderately hot, sweltering	36.28°C	
13:20	Considerably hot	36.28°C	
13:30	Slightly hot	35.50°C	Return indoors
13:36	Comfortable	35.24°C	

Table 3 shows the wrist temperature changing affected by food eating. Data in column of before lunch/supper is tested right before the dinner; data in column of after lunch/supper I is tested right after the dinner; data in column of after lunch/supper II is tested after half an hour of the dinner. The test result shows an increase of wrist temperature after intake of food.

Table 3 Test results of experiment 2

Date	***Before lunch***	***After lunch I***	***After lunch II***	***Before supper***	***After supper I***	***After supper II***
08/07/02	34.21°C	34.72°C	34.46°C	34.98°C	35.76°C	34.72°C
09/07/02	33.95°C	34.46°C	33.69°C	34.98°C	36.02°C	34.72°C
10/07/02	33.95°C	34.98°C	34.72°C	34.98°C	35.76°C	34.98°C
11/07/02	34.46°C	35.24°C	34.72°C	34.46°C	35.50°C	34.72°C
12/07/02	34.21°C	34.98°C	34.46°C	35.24°C	36.02°C	35.50°C
23/07/02	33.95°C	34.21°C	34.21°C	35.50°C	36.02°C	35.24°C

Table 4 shows the wrist temperature changing affected by drinking. The hot water we used in the experiment is about 60°C. The cup is taken in right hand. In this experiment, we can find the thermal comfort of subject is totally changed even though there is no obvious changing in indoor temperature or humidity. Wrist skin temperature increases simply by drinking hot water.

Table 4 Test results of experiment 3

Time	***Feeling***	***Skin temperature***	***Note***
16:46	Comfortable	34.46°C	In air-conditioned room, not drink water
16:47	Comfortable	34.46°C	Begin to drink hot water
16:48	Slightly hot	34.72°C	More hot water
16:49	Hot, sweltering	34.98°C	More hot water
16:51	Considerably hot	35.50°C	More hot water
16:53	Sweltering a lot	35.24°C	Stop drinking
17:00	Comfortable	34.72°C	In air-conditioned room, not drink water

From all these three experiments, the results can show to some extend, the relationship between wrist skin temperature and thermal comfort. Since the body temperature is an objective index, reflecting the real feeling of people, it can satisfy the resident's real demand without compromise.

However, there are still some problems when applying the wrist skin temperature as the only index of human thermal comfort criterion. The inconstancy of body temperature in a whole day may affect our detection and decision. For an average person, his body temperature may fluctuate in period of one day. For women, their body temperature fluctuate are more tricky for their physiological characteristics. Another point is when man in his morbid state, his high fever may cause obvious wrong control decision if no other accessorial strategy is applied.

5.Feasibility in application

The sensor of wrist skin temperature and communication can be realized by modern technology. A wrist human body sensor can be made into watch-shape, integrated with radioactive parts for data transmission. Technology of wireless communication can be applied to send the data to center control unit that control the room air parameters. Currently, Bluetooth is one of such technology that can meet the demand. Bluetooth wireless technology is a worldwide specification for a small-form factor, low-cost radio solution that provides links between mobile computers, mobile phones, other portable handheld devices, and connectivity to the Internet. It is not only because providing freedom from wired connections, but with low cost and power consumption. Equipments complying with the standards of Bluetooth only have power of 1mw (0dbm), when the supported range is 10m. Furthermore, it works in the frequency 2.4G, which is reserved of industry, science and medicine (ISM), together with some communication technology; it can resist the interference and reduce the signal attenuation effectively.

6.Conclusion

The idea of intelligent control strategy of human thermal comfort presented in this paper is still at its infancy stage. A lot of works, like a completed model denoting personal thermal comfort in terms of skin temperature, detailed algorithm of this strategy, exception analysis, designing wrist sensor sample, still left without fully finished. But we believe, with the higher demand of residents and development of technology, a precise, convenient, intelligent, healthy thermal comfortable control strategy is realistic in the coming new century.

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